CSCI 136
Data Structures &
Advanced Programming

Lecture 12

Fall 2018

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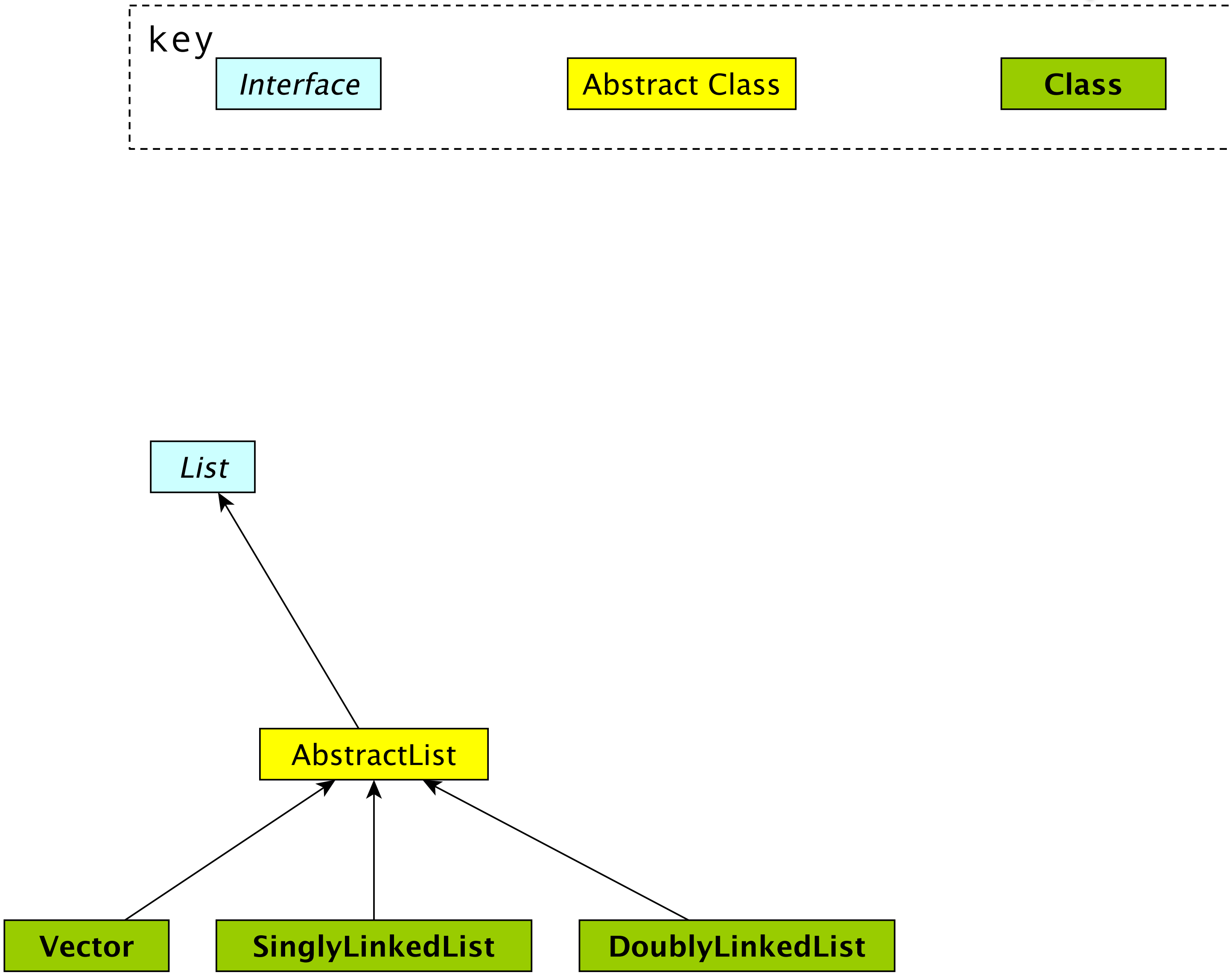
Last Time

- Assertions
- SLL Improvements
  - Tail pointers
  - Circularly Linked Lists
- Doubly Linked Lists
  - Practice with recursion on lists

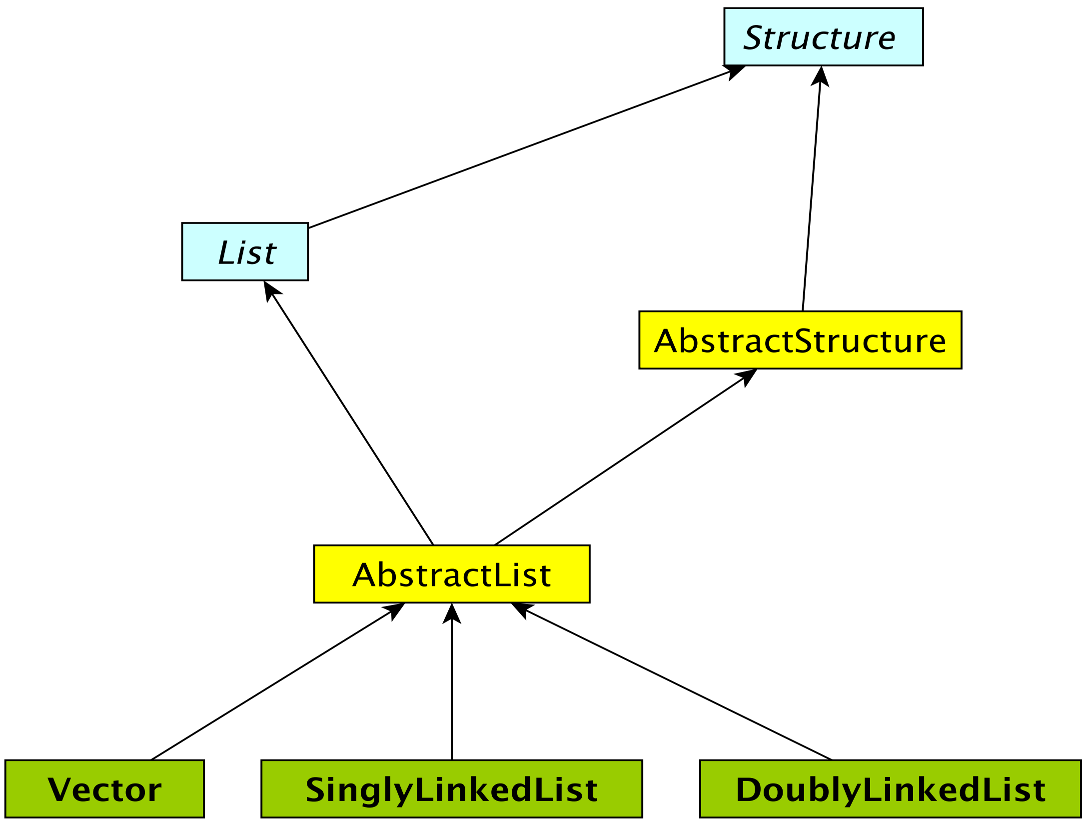
Today's Outline

- The Structure5 Universe
- Search
- The `Comparable` Interface
- "Basic" Sorting
  - Bubble, Insertion, Selection Sorts
- Comparator interfaces for flexible sorting
- More Efficient Sorting Algorithms
  - MergeSort, QuickSort

The Structure5 Universe (almost)



The Structure5 Universe (so far)



Search!

- What is search?
  - Locating an element among our data
- Later we will talk about data structures designed for efficient search
  - Search trees (binary, Tries, B-trees, Be-trees)
  - Hash tables
  - `Dictionary` interface
- But right now we have the `List` interface…

Leveraging Order

- I'm thinking of a number between 1 and 1,000
  - How do you guess?
  - Brute force search (linear scan) is O(n) in the worst case
  - But natural numbers are *ordered*
- When data is sorted, binary search!
- `BinarySearch.java`

Recall : Binary Search

```
public class BinarySearch {

   public static int binarySearch(int a[], int value) {
        return recBinarySearch(a, value, 0, a.length-1);
   }

   protected static int recBinarySearch(int a[], int value, int
                                             low, int high) {
        if (low > high) {                        //value not found
                 return -1;
        } else {
                int mid = (low + high) / 2;      //find midpoint
                if (a[mid] == value)             //found!
                        return mid;
                else if (a[mid] < value)         //search upper half
                        return recBinarySearch(a, value, mid+1, high);
                else                             //search lower half
                        return recBinarySearch(a, value, low, mid-1);
        }
   }
}
```

Recall: Binary Search

- Why does it work?
  - Because items can be ordered they can be sorted then searched based on ordering
- Why is it fast?
  - Cut search space in half with each comparison!
  - Runtime???
    - $O(\log_2(n))$ (# of times we can divide by `2` before we get `1`)
- Precondition: data is comparable and ordered
- If items are not comparable, we typically need to do a *linear search*

Linear Search

- Complexity analysis of linear search:
  - Best case: O(1)
  - Worst case: O(n)
  - Average case: O(n)
  - Why?
    - Assume all locations equally likely
    - The average number of comparisons is

      $(1 + 2 + 3 + \ldots + n)/n = (n+1)/2$, so O(n)
- Here's a *generic* linear search method

Generic Linear Search Method

```
public class LinearSearchGeneric {
 // post: returns index of value in a, or -1 if not found
 // Note the <E> between static and int: a generic method!
    public static <E> int linearSearch(E a[], E value) {
        for (int i = 0; i < a.length; i++) {
            if (a[i].equals(value)) {
                return i;
            }
        }
        return -1;
    }
   public static void main(String args[]) {
        // search a String array
        System.out.println(linearSearch(args, "cow"));
        // search an Integer array
        Integer odds[] = new Integer[] { 1,3,5,7,9 };
        System.out.println(linearSearch(odds, 7));
    }
}
```

Linear vs. Binary Search

- Clearly binary is preferable
- But it requires ordered (i.e., sorted) data.
  - We need *comparable* items
  - Unlike with equality testing, the Object class doesn't define a "`compare()`" method
  - We want a uniform way of saying objects can be compared, so we can write generic versions of methods like binary search
  - Solution: Use an interface!

Comparable Interface

- Java provides an interface for comparisons between objects
  - Provides a replacement for "<" and ">" in `recBinarySearch`
- Java provides the `Comparable` interface, which specifies a method `compareTo()`
  - Any class that implements `Comparable`, provides `compareTo()`

```
public interface Comparable<T> {
    //post: return < 0 if this smaller than other
            return 0 if this equal to other
            return > 0 if this greater than other
      int compareTo(T other);
}
```

Comparable Example

- Player.java
  - Orders basketball players from shortest to tallest
  - compareTo() subtracts their heights… why?

Notes on compareTo()

Notes

- The magnitude of the values returned by `compareTo()` are not important.
  - We only care if the return value is positive, negative, or 0!
- `compareTo()` defines a "*natural ordering*" of Objects
  - There's nothing "*natural*" about it….

- We can use `compareTo()` to implement sorting algorithms!

Comparable & compareTo

- The `Comparable` interface (`Comparable<T>`) is part of the `java.lang` (not `structure5`) package.
- Other Java-provided structures can take advantage of objects that implement `Comparable`
  - Strings, or the `Arrays` class in `java.util`
- Note: Users of Comparable are urged to ensure that `compareTo()` and `equals()` are *consistent*. That is,
  - x.compareTo(y) == 0 exactly when x.equals(y) == true
- Note that `Comparable` limits user to a *single ordering*
- The syntax can get kind of dense
  - See BinSearchComparable.java : a generic binary search method
  - And even more cumbersome….

ComparableAssociation

- Think back to the WordGen lab…
- Suppose we want an *ordered* Dictionary, so that we can use binary search instead of linear scanning
- Structure5 provides a `ComparableAssociation` class that implements `Comparable`.
- The class declaration for `ComparableAssociation` is

…wait for it...

```
public class ComparableAssociation<K extends Comparable<K>, V>
      Extends Association<K,V> implements
      Comparable<ComparableAssociation<K,V>>
```

(Yikes!)

- Example: Since Integer implements Comparable, we can write:

```
ComparableAssociation<Integer, String> myAssoc =
     new ComparableAssociation(567, “Bob”);
```

- We could then sort an array of these!

Sorting Preview: Bubble Sort

- Simple sorting algorithm that works by ascending through the list to be sorted, comparing two items at a time, and swapping them if they are in the wrong order
- Repeated until no swaps are needed
- Gets its name from the way larger elements "bubble" to the end of the list

Bubble Sort

5 1 3 2 9

- First Pass:
  - (**5** 1 3 2 9) → (1 **5** 3 2 9)
  - (1 **5** 3 2 9) → (1 3 **5** 2 9)
  - (1 3 **5** 2 9) → (1 3 2 **5** 9)
  - (1 3 2 **5** 9) → (1 3 2 5 **9**)
- Second Pass:
  - (**1** 3 2 5 9) → (**1** 3 2 5 9)
  - (1 **3** 2 5 9) → (1 2 **3** 5 9)
  - (1 2 **3** 5 9) → (1 2 3 **5** 9)
- Third Pass:
  - (**1** 2 3 5 9) -> (**1** 2 3 5 9)
  - (1 **2** 3 5 9) -> (1 **2** 3 5 9)
- Fourth Pass:
  - (**1** 2 3 5 9) -> (**1** 2 3 5 9)

http://www.youtube.com/watch?v=lyZQPjUT5B4

Bubble Sort

- Simple sorting algorithm that works by ascending through the list to be sorted, comparing two items at a time, and swapping them if they are in the wrong order
- Repeated until no swaps are needed
- Gets its name from the way larger elements "bubble" to the end of the list
- Time complexity?
  - $O(n^2)$
- Space complexity?
  - O(n) total (no additional space is required)